Potential Impacts from Reflection of Proposed Mount Signal Solar Farm I (82 LV)
Draft Date: May 24, 2011

KEY FINDINGS

- Based on the geometric configuration of the panels relative to the path of the sun and the inherently low reflectively of flat-plate photovoltaic modules it is highly unlikely that the proposed projects will result in hazardous glare conditions.
- Flat-plate photovoltaic solar panels are engineered to absorb, not reflect, sunlight. A panel with a single layer of anti-reflective coating reflects less than 10% of the sunlight striking it. By way of comparison agriculture vegetation reflects between 18 and 25% of solar radiation.
- In order to maximize electricity production, panels are oriented toward the south and facing the sun, resulting in angles of reflection well above the nearby roads and the built environment.

8minutenergy, LLC asked Good Company, a sustainability research and consulting firm, to prepare a high-level analysis of the potential for hazardous glare conditions at the proposed site for the Mount Signal Solar Farm I which is located 2.5 miles west of Calexico in Imperial County, California. The project site is comprised of four parcels of land with a total area of 1,403 acres. See Appendix A for aerial photographs of the site.

The proposed project is a 200-megawatt ground-mounted photovoltaic array that would make use of flat-plate, monocrystalline silicon photovoltaic modules. In conducting the reflection analysis, Good Company considered two design alternatives: 1) a south facing fixed-axis array and 2) a single-axis polar mounted array that partially tracks the path of the sun from east to west.

This analysis focused on the direct reflection impacts from the Mount Signal Solar Farm I project on nearby roads and a residential neighborhood on the western edge of Mexicali, Mexico. The reflection impacts on aircrafts using Calexico International Airport are addressed in a separate Reflectivity Analysis completed by Aztec Engineering in April 2011. See that report for details.

Reflectivity of Flat-plate Photovoltaic Solar Panels

Flat-plate photovoltaic solar panels are designed to absorb sunlight in order to convert it into electricity. Monocrystalline silicon wafers, the basic building block of most photovoltaic solar modules, absorb up to seventy percent of the sun's solar radiation in the visible light spectrum[1]. Solar cells are typically encased in a transparent material referred to as an encapsulant and covered with a transparent cover film, commonly glass. The addition of these protective layers further reduces the amount of visible light reflected from photovoltaic modules. Photovoltaic panels are using the absorbed energy in two ways; 1) the panels generate electricity, and 2) the mass of the panels heat up.

In order to maximize the efficiency of electricity production, photovoltaic manufacturers design their panels to minimize the amount of reflected sunlight. The most common methods to accomplish this are the application of anti-reflective coatings and surface texturing of solar cells. Combined, these techniques can reduce reflection losses to a few percent.[2] Most solar panels are now designed with at least one anti-reflective layer and some panels have multiple layers.

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[1] Luque and Heeds. 2003. *Handbook of Photovoltaic Science and Engineering*. Wiley and Sons, New Jersey.
[2] Ibid.

Comparison of the Reflectivity of Solar Panel to the Surrounding Environment

One measure of the reflectivity is albedo — the ratio of solar radiation across the visible and invisible light spectrum reflected by a surface. Albedo varies between 0, a surface that reflects no light, and 1, a mirror-like surface that reflects all incoming light. Solar panels with a single anti-reflective coating have a reflectivity of around .10.[3] By comparison, sand has an albedo between .15 and .45 and agricultural vegetation has an albedo between .18 and .25.[4] In other words, the solar panels have a lower reflectivity than the area's prevailing ground cover, agricultural crops.

Visibility of a Direct Reflection of Sunlight for South Facing Fixed Mount Panels

In order to maximize electricity production, fixed (non-tracking) solar panels must be oriented toward the sun as much as possible. Per project specifications, this analysis assumes that the panels will face polar south at a tilt of 25 degrees above horizontal.

The position of the sun relative to the solar panels will vary by the time of day and time of year. As a result, the angle of direct reflection from the panels will also vary accordingly. The greatest likelihood of a low-angle of direct reflection that might impact the built environment occurs mid-day on the summer solstice when the sun is at its highest point in the sky and the angle of reflection is lowest (see Figure 1 below). The potential impact at that moment is the best proxy for maximum impact overall.

During summer solstice at the proposed projects' latitude, the sun's solar elevation is approximately 80 degrees[5]. With the sun at this height, the resulting angle of direct reflection is approximately 50 degrees above the horizon. It is highly unlikely that any objects in the built environment near the project site would be adversely affected by a direct reflection of sunlight from this angle, including vehicles traveling on nearby roads or residential neighborhoods on the western edge of Mexicali. Indeed, there are no structures of combined height and proximity to experience this direct reflection.

During the winter months, when the sun travels across the sky at lower angles relative to the horizon, the angle of reflection and the resulting height of the reflected sunlight are higher. At midday on the winter solstice at the proposed projects' latitude, the sun's solar elevation is approximately 34 degrees. At this angle of elevation, the resulting angle of reflection is 96 degrees. At this angle of reflection, the height of the reflected sunlight would exceed 190 feet in elevation at a distance of only 20 feet away and the further away from the array the greater the height of the reflected sunlight.

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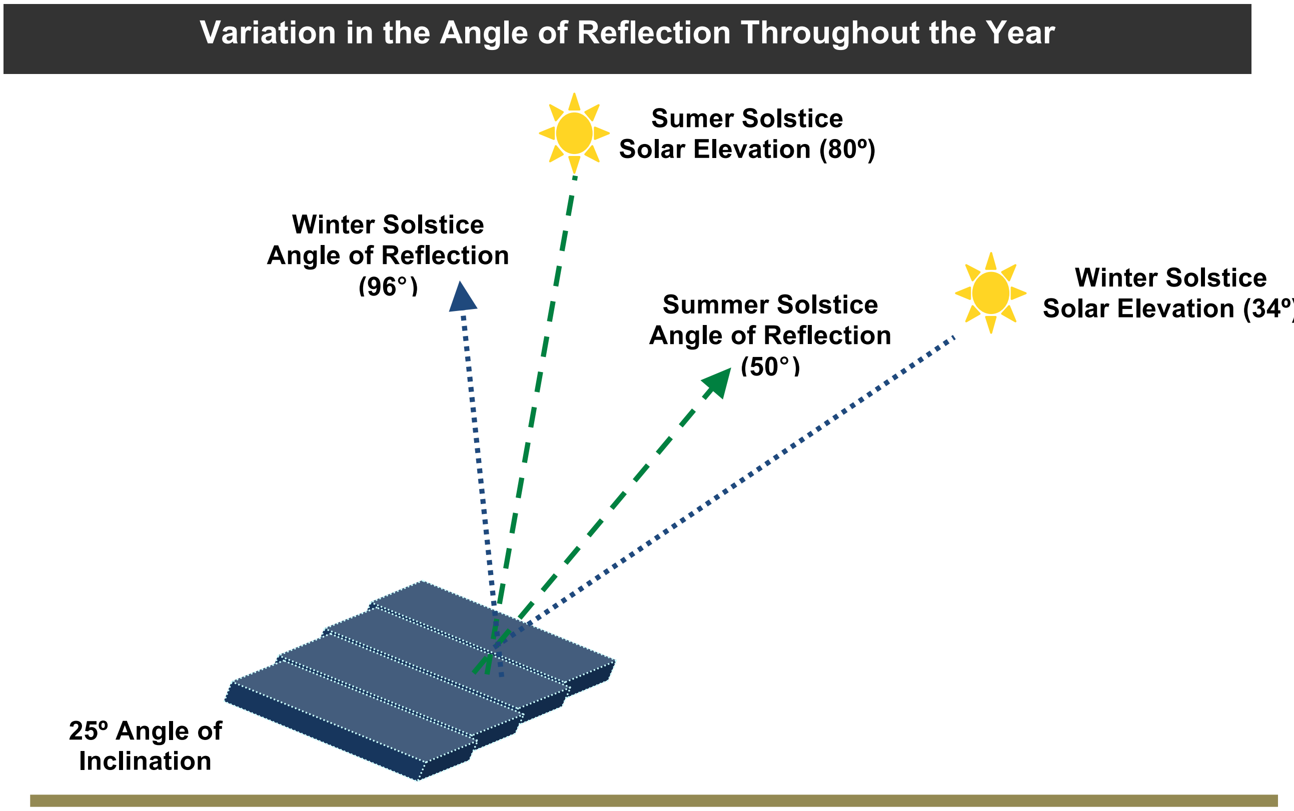
[3] Lanier and Ang. 1990. *Photovoltaic Engineering Handbook*. New York: Taylor & Francis.
[4] Budikova, Dagmar. 2010. "Albedo." *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. Retrieved July 5, 2010 at http://www.eoearth.org/article/Albedo.
[5] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 33.16 degrees north. A copy of the chart is attached at the end of this document.

Figure 1: The range of the sun's angle-of-reflection depending on the time of year.



The following narrative provides the height of direct reflection relative to nearby points of concern for June 21st (the date that produces the lowest angles of direct reflection).

At a distance of only 30 feet (the approximate distance from the southern edge the Parcel II array to the edge of the utility road to the south), the height of the reflected sunlight from the array would exceed 36 feet in elevation, well above the California truck height limit of 14 feet. It's important to note that roads in the immediate vicinity of the arrays are non-paved utility roads, not major transportation corridors and as such is not expected to support significant passenger or commercial traffic.

The built structure closest to the Mount Signal Solar Farm I site is a single residence 0.4 of a mile due south (off of Rockwood Road) off the southeastern corner of Parcel III (lot 052-210-016). At this distance, the height of direct reflection is over 2,200 feet (or ~0.4 of a mile). The closest group of structures to the Mount Signal Solar Farm I is a residential neighborhood on the western edge of Mexicali, Mexico. These homes are 0.9 of a mile due south from the southern edge of the array in Parcel II (specifically lots 059-130-004 and 059-130-005). At this distance, the height of direct reflection is over 5,300 feet (or ~1 mile).

Figure 2 shows Parcel I and II of the Mount Signal Solar Farm and points A through F indicating different distances from the panels. Figure 3 shows the corresponding elevation of direct reflection at each point indicated in Figure 2.

Figure 2: Map of the points listed in Figure 3 and the “on the ground” distance from each point to the array.

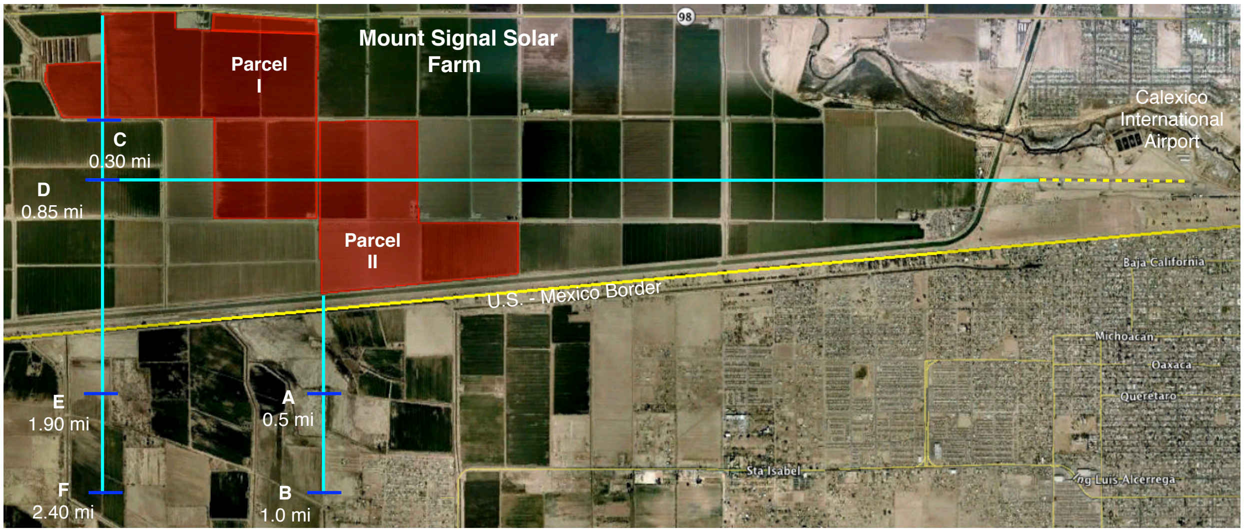


Figure 3: Elevation of direct reflection for the points show on Figure 2.

Point on Figure 2	Elevation of Direct Reflection	
	miles	feet
A	0.60	3,147
B	1.19	6,294
C	0.36	1,890
D	1.01	5,349
E	2.26	11,954
F	2.86	15,101

Visibility of an Indirect Reflection of Sunlight

While this analysis focuses on direct reflection in theory, we must also consider the potential for indirect reflections (the visibility of diffused sunlight on the surface of the panels). As with the potential for direct reflections, indirect reflections are not a significant concern[6]. Indirect reflections are by definition significantly less intense— for example, moving just 30 degree off a direct reflection lowers light intensity by nearly 80%[7]. While at certain times of the day an observer would have a view of an indirect reflection, the relative intensity of the reflection would not be significant or a concern. Additionally the project developer has proposed to construct an 8-foot slatted fence around the perimeter of the project further obscuring the peripheral view of the project (an any indirect reflection).

Comparison of Fixed Mount and Single-axis Tracking Mount on Direct Solar Reflection

Like the fixed-axis array configuration, the panels of a single-axis tracking array would also have an angle of inclination of approximately 25 degrees. Since this angle of inclination remains constant between the two configurations, the lowest potential angle of reflection remains the same. As with a fixed-axis array, the greatest potential for a low angle of reflection that might impact the built environment occurs mid-day on the summer solstice when the sun is at its highest point in the sky.

The key difference between a fixed-axis and single-axis tracking configuration is the cardinal direction of reflected sunlight. At mid-day on the summer solstice, the time of year most likely to produce a low angle of reflection, both configurations would be facing south and reflect light back in the same direction. At other times of the year the angles of reflection would be higher and as such the height of direct reflection would increase compared to summer solstice.

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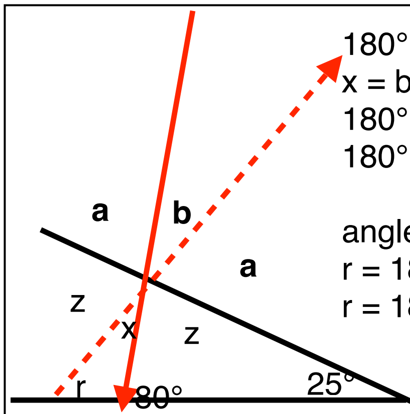
[6] A number of other studies conducted for proposed solar projects have sought to quantify the potential for the diffuse reflection of sunlight from the surface of solar panels and reached similar conclusions. For additional information see “Panache Valley Solar Farm Project Glint and Glare Study” (www.panochesolar.info/app/jun2010/Glint_Glare_Study.pdf) and “Topaz Solar Farm Reflection Study” (http://www.slocounty.ca.gov/Assets/PL/Optisolar-Topaz+Solar+Farm/Documents/Application+Submittal+$!232/Attachment+C+-+Topaz+Solar+Farm+Reflection+Study.pdf).

[7] TrinaSolar. “Reflection Coefficient of Trina Solar Modules.” Personal communication with Thomas Houghton, June 30, 2010.

Angle of Direct Reflection Off Panels

According to the sun path diagram charting the sun's movement at the proposed project's latitude, the sun is shining at its highest point at 12:00 PM on the summer solstice (June 21).[8] At this point the sun is shining at an 80-degree angle directly upon the south facing solar panels. Note that the fixed-tilt solar panels are set at 25° above horizon.

Figure 4: Angle of direct reflection on summer solstice (June 21).



180° - (80° + 25°) = z = 75°
x = b   z = a
180° - 2a = b
180° - 2(75°) = 30° = b

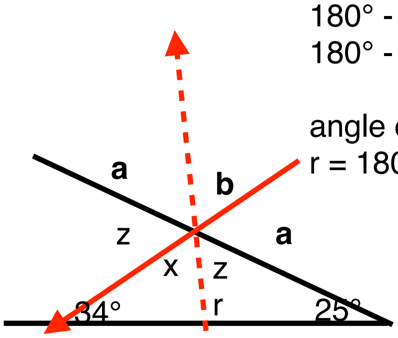
angle of reflection = r
r = 180° - (x+z) - 25°
r = 180° - (30°+75°) - 25° = 50°

Figure 4 depicts this reflection. All angles within a triangle add up to 180°. From this rule it is simple algebra to obtain that **z** equals 75°. Because **a** and **z** are vertical angles, **a** also equals 75°. Once **b** is calculated (a flat plane also equals 180° so subtracting **180°– 2a** equals **b**) the calculation of the angle of the sun's reflection is easy to complete using the same formula (**180°– (z + x) – 25°**). The angle of the sun's reflection is 50°.

Figure 5: Angle of direct reflection on winter solstice (Dec. 21).

180° - (34° + 25°) = x + z = 121°
180° - 121° = z = 59°
x = b   z = a
180° - 2a = b
180° - 2(59°) = 62°

angle of reflection = r
r = 180 - (25° + 59°) = 96°



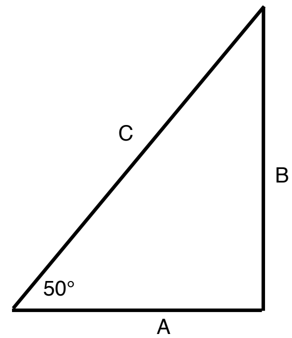
Similar calculations are performed to determine the angle of the sun's reflection when the sun hits the solar panels at a low point (see the Figure 5 to the left, a 34-degree angle). From determining that **x** plus **z** equals 121° (**180°– 34°– 25°**) and looking at the vertical angles (**x = b**) and (**z = a**), it is then possible to calculate that the angle of the sun's reflection is 96° (**r = 180°– z – 25°**).

[8] Based on a Sun Path Chart produced using the University of Oregon Solar Radiation Monitoring Laboratory's Sun Chart software available on-line at http://solardat.uoregon.edu/SunChartProgram.php and assuming a latitude of 32.40 degrees north.

Determining the Height of Reflection

The lowest potential reflection angle, determined to be 50 degrees, was used to estimate the height of the sun's reflection. Triginometry calculations are used to project the height of the reflection. It is important to point out that there are no notable elevation rises surrounding the sited Mount Signal Solar Farm. Figure 6 to the right shows the basic calculations to determine the height of the sun's reflection. In the visual, A is representative of the horizontal distance. Any distance measurement can be input into the formula to find B, which represents the height of the sun's refelction at the distance input.

Figure 6: Calculation to determine direct reflection.

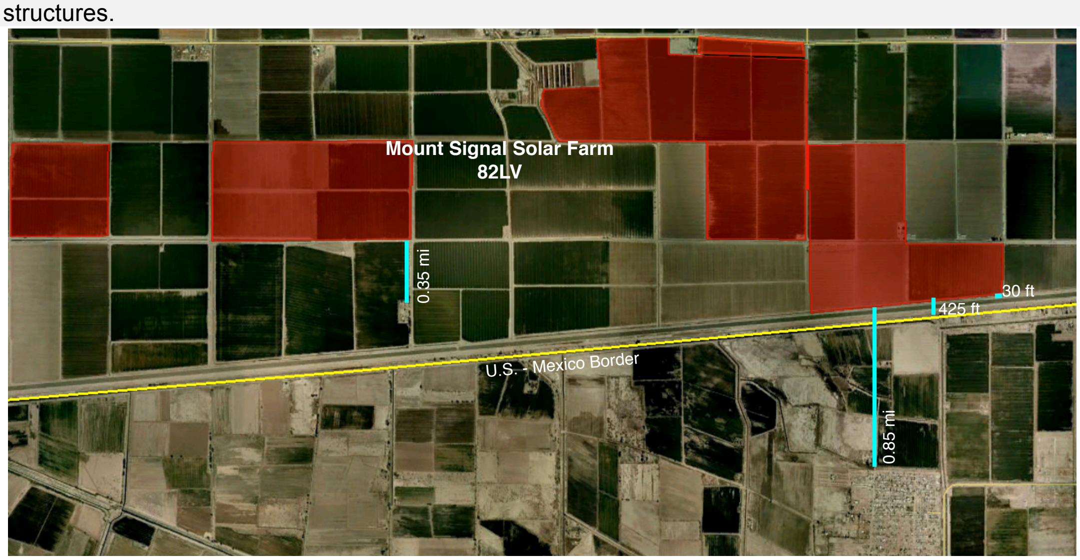


$\tan(50°) = B / A$

$B = A \tan(50°)$

Figure 7 is an aerial picture of the sited Mount Signal Solar Farm from Google Earth (below) has overlaying lines to show clearly the U.S. – Mexico Border (yellow line) as well as the four parcels which serve as the boundaries for the panel arrays in this project. Figure 5 also shows distances from the southern edge of the panel arrays to nearby roads and built structures (blue lines). The bullet points below Figure 4 describe the height of the direct reflection at the various distances shown by the blue lines.

Figure 7: Aerial image of the Mount Signal Solar Farm I project array locations and distances to nearby built structures.



- At 30 feet from the solar panels the height of the reflection is at 35.8 feet or higher (depending on the time of year). This is the approximate distance from the panels to the utlity road that runs parrellel to the southern edge of Parcel II.

- At 425 feet from the solar panels the height of the reflection is 506.5 feet or higher. This is the distance from the southern edge of Parcel II to the Mexican boarder.

- At 0.35 miles from the solar panels the height of the reflection is 0.417 miles (2,202 feet) or higher. This is the distance from the southern edge of Parcel III to the closest building.

- At 0.85 miles from the solar panels the height of the reflection is 1.013 miles (5,349 feet) or higher. This is the distance from the southern edge of Parcel III to the closest group of buildings (a neighborhood on the far western edge of Mexicali, Mexico).

Panels On a Single-axis Tracker

The proposed project may also feature panels mounted on single-axis polar trackers enabling the panels to rotate 45° off of due south. The single-axis tracker will widen the area of reflection, but no reflection will fall below the lowest angle of 50°. The visual below depicts this difference with the blue dashed lines representing the reflection from the panels mounted on the single-axis tracker and the orange dotted lines representing the panels at a set tilt.

Figure 8: Direction of direct reflection based from single-axis tracker (blue) and fixed (orange).